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One-dimensional longitudinal–torsional vibration converter with multiple diagonally slitted parts

Jiromaru Tsujino*, Tetsugi Ueoka, Kenichi Otoda, Atsushi Fujimi

Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan

Abstract

For increasing the available vibration velocity of the one-dimensional longitudinal–torsional vibration converter, a new type of complex vibration converter with multiple slitted parts installed in the positions avoiding longitudinal nodal positions along the converter for decreasing the maximum vibration stress level at the vibration nodal part was studied. The free end of the converter vibrates in an elliptical or circular locus. Complex vibration systems with elliptical to circular or rectangular to square loci can be applied effectively for various high-power applications, including ultrasonic welding of metal or plastics, ultrasonic wire bonding of IC, LSI and electronic devices, and also ultrasonic motors. The converter with multiple slitted parts was improved in the vibration stress level and the quality factor compared with the converter with single slitted part.

Keywords: Circular vibration locus; Complex vibration; Complex vibration ultrasonic welding; Longitudinal–torsional vibration converter; Ultrasonic motor; Ultrasonic plastic welding; Vibration converter with diagonal slits

1. Introduction

Complex vibration systems with elliptical to circular or rectangular to square loci are effective for various high-power applications. A one-dimensional longitudinal–torsional vibration converter with a slitted part at longitudinal vibration nodal area driven by a longitudinal vibration system is useful for high-power applications including ultrasonic welding of various materials, ultrasonic wire bonding of bonding of IC, LSI and electronic devices, and also ultrasonic motors [1–4]. A new type of converter with multiple slitted parts, for improving the vibration characteristics and increasing the available vibration velocity of the converter, is studied. The slitted parts are installed in multiple positions avoiding longitudinal nodal positions along the converter for decreasing the maximum vibration stress level at the vibration nodal part. Using multiple slitted parts, the maximum vibration stress along a converter decreases and the quality factor increases, and the maximum vibration amplitude increases significantly at the same driving voltage [5]. The converter has superior vibration characteristics because the maximum vibration stress along the converter is decreased in comparison to the converter with a slitted part, and the maximum vibration amplitude of the converter increases significantly. Vibration locus, and vibration velocity and phase distributions along the converter were measured by two laser Doppler vibrometers. The new-type converters were used for ultrasonic plastic welding and ultrasonic motors.

The maximum available vibration velocity increased significantly with the new converter. Welding characteristics of plastic materials were improved by the complex vibration converter.

The longitudinal and torsional vibration amplitudes of a 15 mm diameter of a new converter for an ultrasonic motor increased to about 12 μm (peak-to-zero value) from 6 μm with a former converter under the same driving voltage 60 Vrms at 55 kHz.

The converter with multiple slitted parts was found to be effective for improving the vibration characteristics and increasing the available complex vibration velocity.

2. Configurations of vibration converters

Configurations of two examples of the vibration converters 20 mm in diameter and 79 mm in length, with

* Corresponding author. Tel.: +81-45-481-5661; fax: +81-45-491-7915.
E-mail address: tsujino@cc.kanagawa-u.ac.jp (J. Tsujino)

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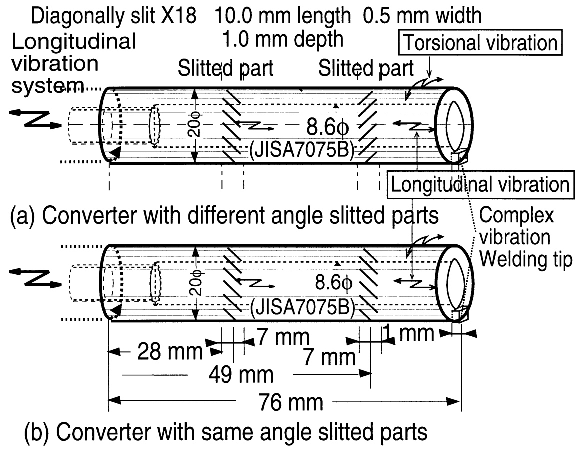

Fig. 1. Various one-dimensional longitudinal to torsional vibration converters with double slitted parts.

slitted parts that were installed avoiding a longitudinal nodal part, are shown in Fig. 1. The cylindrical longitudinal–torsional vibration converters, made of aluminum alloy (JISA7075B), had two slitted parts on both sides of a longitudinal vibration nodal part at its circumference. The converters were driven by a longitudinal vibration source. Various converters with (a) different and (b) the same angle diagonally slitted parts were made in the trials. The vibration converter part had 18 diagonal slits of 45 or 135°, 10 mm width and 0.5 mm width were cut along its circumference using an electrosparking machine. The slit depth was altered from 1.0 to 3.0 mm. The free edge part of the converter vibrated longitudinally and torsionally and vibrated in an elliptical locus.

3. Vibration characteristics of the converters with two slitted parts

The free admittance loops of the total vibration systems with the converters [Fig. 1(a) and (b)] were measured. The quality factor and motional admittance, $|Y_{mo}|$, of the vibration system with a converter with different angle slitted parts (a) and the same angle slitted parts (b) were about 600 and 30 mS under welding conditions of two 1.0 mm thick polypropyrene sheets with a static pressure of 890 kPa. The admittance loops of the vibration system with the converters show single circular shapes because the resonance frequencies of the longitudinal and torsional vibrations are close. The quality factors and motional admittances of the both systems are large. Elliptical loci were obtained at the free edges of the converters.

4. Complex vibration ultrasonic plastic welding

4.1. Vibration characteristics of a complex vibration converters

Fig. 2 shows the relationship between driving frequency and longitudinal and torsional vibration velocity of a complex vibration system with the vibration converter (a). The driving voltage is kept constant at 20 Vrms. Longitudinal and torsional vibration velocities have maximum values at different frequencies at around 26.3 and 26.4 kHz. The elliptical locus is obtained at the free edge of the converter.

Torsional and radial vibration velocity distributions at 26.8 kHz along a complex vibration converter with double slitted parts (a) and (b) are shown in Fig. 3. One torsional vibration velocity nodal part is within a left slitted area, and the vibration velocities have maximum values at the free edge.

The radial vibration velocity distribution along a complex vibration converter with double slitted parts

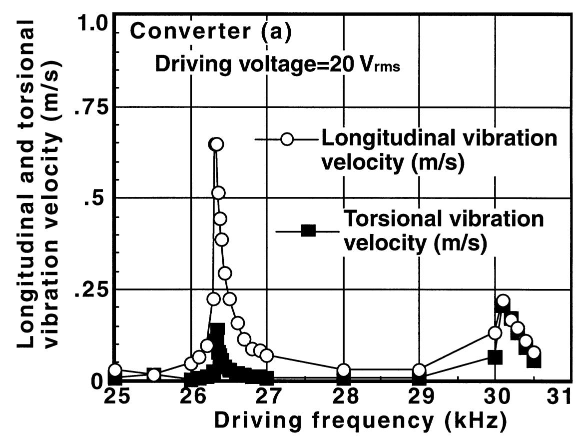

Fig. 2. Torsional and radial vibration velocity distributions along complex vibration converters (a) and (b). Driving voltage: 20 Vrms.

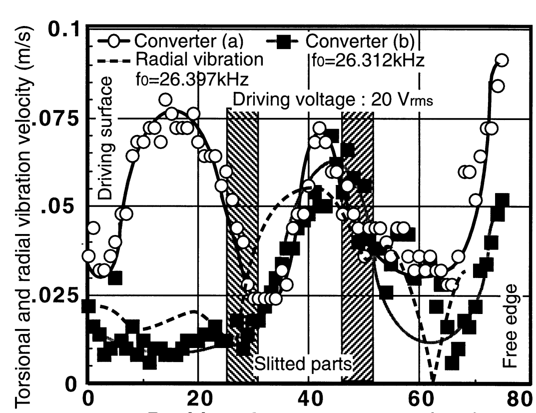

Fig. 3. Relationship between driving frequency, and longitudinal and torsional vibration velocity of a complex vibration system with a vibration converter (A). Driving voltage: 20 Vrms.

(a) is also shown in Fig. 3 (dotted line). A radial vibration velocity maximum position means a longitudinal vibration nodal position, and the longitudinal nodal position is positioned between two slitted parts. The two slitted areas exist out of the longitudinal nodal position where the vibration stress has a maximum value along the converter.

4.2. *Welding characteristics of complex vibration ultrasonic plastic welding*

The relationship between welding time, specimen deformed thickness at the welded parts and the weld strength of the lapped polypropyrene sheets (1.0 mm in thickness), welded using a 27 kHz complex vibration system with a converter (a) and (b), is shown in Fig. 4. The weld strengths obtained by the system with converter (a) are larger than those with a converter (b). The welding time required becomes shorter using the vibration system (a) with a larger torsional vibration component. The decrease in specimen deformed thickness at the welded parts roughly corresponds to the obtained weld strength. Specimens were welded in a shorter welding time using a complex vibration system compared with a longitudinal vibration system. Complex vibration is effective for ultrasonic welding of plastic materials as for metal materials.

5. Ultrasonic motors with a longitudinal–torsional converter

5.1. *Configuration of ultrasonic motors*

The configurations of the ultrasonic motors and vibration converters, 15 mm in diameter, are shown in Fig. 5. Fig. 5(a) and (b) show the configurations of 15 mm diameter motors using a converter with single and double slitted parts. In the case of the converter with single slitted part, the slitted part is positioned at a nodal position of the longitudinal vibration along the cylindrical longitudinal–torsional vibration converters. On the contrary, in the case of the converter with two slitted parts, the slitted parts are positioned avoiding the longitudinal vibration nodal position. The converter with diagonal slits is driven by a longitudinal vibration source of two piezoelectric ceramic (lead–zircon–titanate; PZT) disks, 15 mm in diameter and 5.0 mm in thickness. The vibration converter slitted part has 12 diagonal slits of 45 or 135° and 0.5 mm in width and 10 or 5 mm in length, cut by an electrosparking machine along the circumference of these converters fabricated from aluminum alloy (JISA7075B). The slit depths of the 15 mm diameter converter are altered from 1.5 to 3.5 mm. The free edge of the converter vibrates longitudinally and torsionally and vibrates in an elliptical locus.

The PZT longitudinal vibration transducers, a longitudinal vibration rod with a flange for supporting the motor and a slitted cylinder are clamped by a connecting bolt. The driving part of the converter and the rotor part are statically pressed using corned disk springs by a center bolt and nuts. The driving surfaces of the converter (JISA7075B) and the rotor (steel: SKD-61 or SK-4: tempered) are ground to be flat and smooth using 1500–2000 mesh polishing powder.

5.2. *Vibration characteristics of 15 mm diameter ultrasonic motors*

The longitudinal and torsional vibration amplitudes at the free edge of these converters were measured by two laser Doppler vibrometers when the driving frequency was altered. These converters have near-resonance frequencies of the longitudinal and torsional vibrations similar to Fig. 2. The largest longitudinal vibration amplitudes of the converter of single and two slitted parts without a rotor part were about 6 and 12 μm (peak-to-zero value) at frequencies of 50–55 kHz. The largest longitudinal vibration amplitudes of these converters with a rotor part are about 3 and 9 μm at frequencies near to 55 kHz. The largest vibration amplitudes of a converter with double slitted parts are about two to three times compared with the amplitudes of a converter with single slitted part.

5.3. *Vibration loci at the driving surface of the converter*

In these cases, the longitudinal vibration is partially converted to torsional vibration at the slitted parts, and the cylinder part of the converter vibrates longitudinally and torsionally. The vibration locus at the free edge is determined by the vibration phase difference between these vibrations. Vibration loci at the driving surfaces of longitudinal–torsional converters were measured using two laser Doppler vibrometers (~20 MHz) that

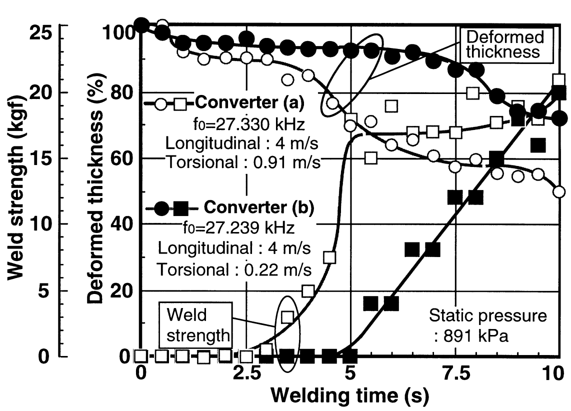

Fig. 4. Relationship between welding time, deformed weldment height and weld strength of the lapped polypropyrene sheets (1.0 mm in thickness), welded using a 27 kHz complex vibration system with a converter (a) and (b).

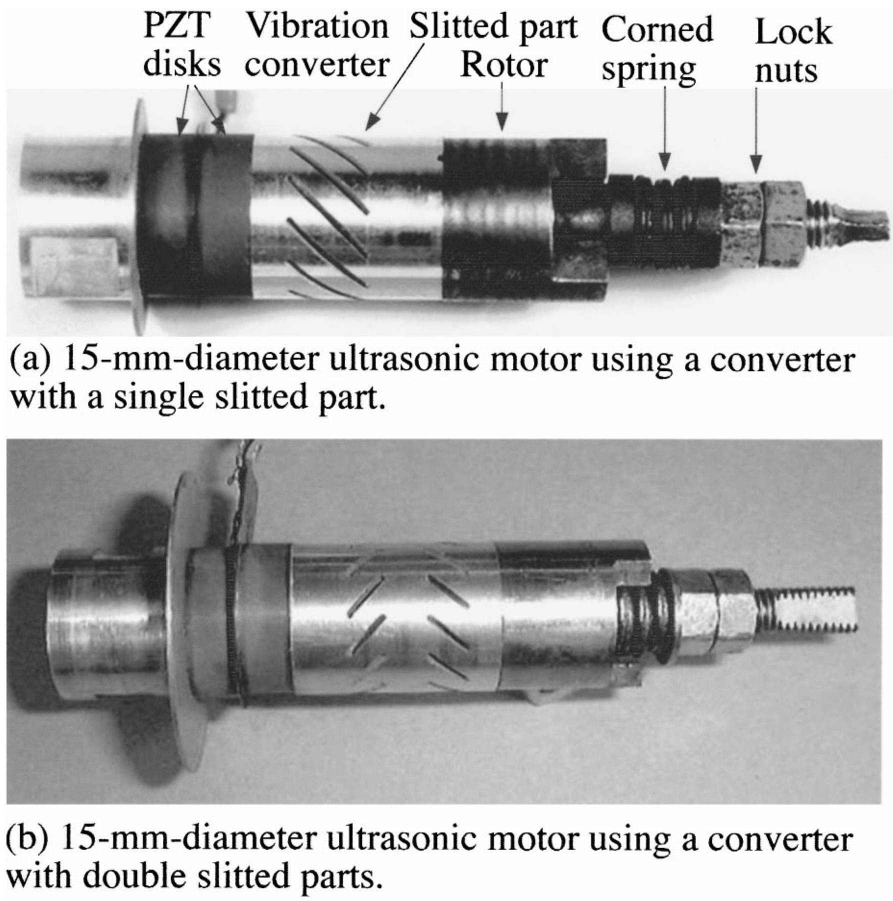

Fig. 5. Configurations of 15 mm diameter ultrasonic motors using a longitudinal–torsional vibration converter with single slitted part (a) and double slitted parts (b).

detect longitudinal and torsional vibrations independently. The vibration locus is shown on a digital memory oscilloscope screen as a Lissajous figure. Fig. 6 shows the vibration loci at the driving surfaces of converters with double slitted parts of 3.3 mm depth and 5 mm length of the ultrasonic motor of 15 mm diameter in the driving frequency 55.1 kHz (without a rotor) and 54.26 kHz (with a rotor). The vibration locus amplitude at the driving surfaces of converter decreases slightly when the ultrasonic motor rotates.

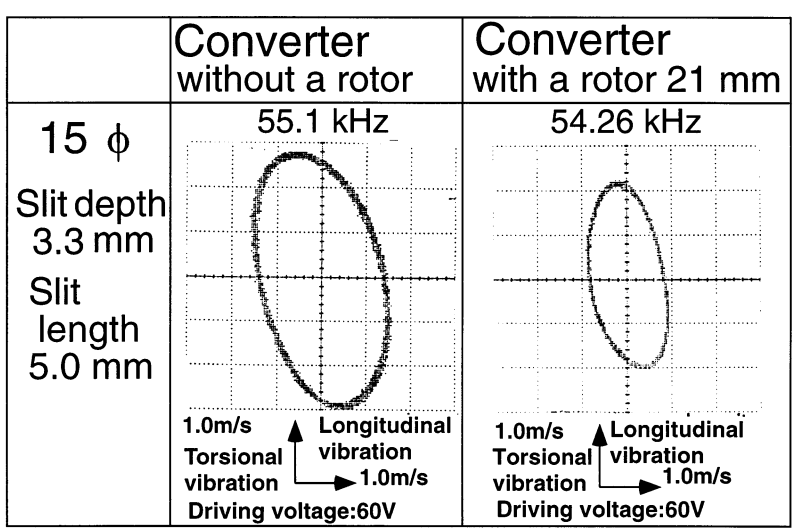

Fig. 6. Vibration loci at a driving part of a 15 mm diameter converter with and without a rotor part.

6. Conclusion

For increasing the available vibration velocity of the complex vibration converter, a new type of converter with multiple slitted parts was studied.

This converter has multiple slitted parts that are installed in multiple positions, avoiding nodal positions along the converter for decreasing the maximum vibration stress level at the vibration node part. The welding characteristics of ultrasonic plastic welding using complex vibrations were studied. Also, 15 mm diameter ultrasonic motors using converters with double slitted parts were tested.

The longitudinal vibration nodal part was located between two slitted parts of the converters. The driving surface of the converter and the ultrasonic motor with double slitted parts vibrated at higher vibration velocities than those with a single slitted part at the same driving voltage.

The converter with double slitted parts significantly improved the ultrasonic welding characteristics of plastic materials. The 15 mm diameter ultrasonic motor, together with a converter with double slitted parts, rotated at over 300 rpm.

The converters with multiple slitted parts were found to be effective for improving the vibration characteristics and increasing the available complex vibration velocity.

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